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Final Technical Report
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During the last years my work on IUE spectra was mainly concerned with two topics:

1. The study of stellar chromospheres and transition layers
2. The study of Cepheid companions in order to derive the masses of the Cepheids.

The studies in both fields still continue.

1. Stellar Chromospheres and Transition Layers

Our studies were concentrated on F stars, because basic changes seem to occur in the heating mechanisms for main sequence stars with spectral types around F5 as indicated by several observations: For earlier stars the chromospheric and transition layer emission depends only on the effective temperature but not on the rotational velocity, while for later spectral types it also depends on rotational velocities.

For spectral types later than F7 periodic variations are observed for the chromospheric CaII H and K line emission. Such periodic variations are not seen for early F stars. These variations are attributed to the presence of magnetic activity centers with strong CaII H and K emission, which appear and disappear from the visible hemisphere due to stellar rotation.

Since the dependence on rotational velocities is generally related to magnetic activity, these observations suggests that for spectral types earlier than F5 the heating is mainly due to processes unrelated to the presence of magnetic fields, presumably acoustic heating where the acoustic waves are generated within the hydrogen convection zone. For later spectral types heating mechanisms related to magnetic fields and stellar activity may become of major importance. We were interested to find out at which spectral type exactly this transition takes place, and whether this transition might occur at slightly different spectral types for stars of different ages. We also wanted to clarify whether there is a separate dependence of the chromospheric and transition layer emission on age and rotation. Since rotation and age are statistically correlated the dependences on both parameters are confused in the literature. It therefore seemed important to us, to study groups of stars with known ages, like stars in clusters, and study the dependence of their emission on rotation. For different clusters we can then compare stars with given effective temperature and given rotational velocity and study their dependence on age.

We studied mainly Hyades main sequence stars. We found for the chromospheric CaII H and K emission a dip at spectral type F5, in near agreement with the dip in the Li abundances, see Figure 1. We also found relative minima in the transition layer emission of the CIV and CII lines as well as in the coronal X-ray emission, see Figure 2, but for stars near the B-V for the minima of these latter emissions we also find stars with normal emission in the CII and CIV lines and the X-rays. Unfortunately we did not get the observing time to study more stars in this spectral region in order to understand why the emissions in the different layers appear to behave differently for B-V values around 0.45.

In order to get more information about the relation between the heating mechanisms in different layers we also studied the relation between the X-ray and the chromospheric CaII emission. We found that for stars with B-V $<$ 0.45 there is a power law relation between the CaII emission and the X-ray emission, but at B-V=0.45 the X-ray emission abruptly increases by a factor of 2, while the CaII emission decreases. For larger values of B-V the CaII emission increases more slowly with increasing X-ray emission than for the earlier F stars, see Figure 3, suggesting that a new heating mechanism adds to the heating of the coronae, while not influencing the chromospheric heating very much.

Why does this new heating mechanism start abruptly at B-V=0.45? We think the explanation is the abrupt increase in the depth of the outer convection zone due to the merging of the hydrogen and helium convection zones, which are separate for the early F stars. The sudden increase in the convection zone depth apparently leads to much larger magnetic activity structures and possibly large coronal loops, which are strong X-ray emitters. The larger activity regions also lead to the observed periodic variations in the CaII emission, due to the stellar rotation, which is not observed for early F stars.

It is, however, surprising that for the later F stars in the Hyades the transition layer emission does not depend on the rotation rate of the stars, as might be expected, if magnetic heating mechanisms are mainly responsible for the heating of the chromospheres, transition layers and coronae, and magnetic activity is related to stellar rotation. It is believed that this is due to saturation for the young Hyades stars. On the other hand it is well known that the chromospheric CaII emission decreases with increasing age. It is stronger for the very young Pleiades stars than for the Hyades. The Ca II emission in the Hyades therefore does not seem to be saturated. We need to study the transition layer emission of the Pleiades in order to find out, whether the transition layer emission for these young stars is indeed saturated.

If the heating in the early F stars is due to acoustic heating, it remains a puzzle why then the chromospheric emission for these stars appears to decrease with increasing age of the stars. The convection is not expected to decrease with increasing age. Further studies are needed to clarify this point.

In summary we think, that we found many interesting, hitherto unknown correlations and theoretical insights, but there are still many open questions concerning the heating mechanisms for the chromospheres, transition layers and coronae.

We intend to continue these studies with existing archival data.

2. Studies of Cepheid Binaries

We are continuing the study of Cepheid binaries with the aim to determine Cepheid masses. With HST we are measuring the orbital radial velocities of the main sequence companions for several Cepheids. The ratio of the orbital velocities for the Cepheids and the companions gives the mass ratio. For the main sequence companions their spectral types determine their masses. We have made a large effort to determine accurate spectral types for our target stars. For the companion of S Muscae the ultraviolet continuum energy distribution, when dereddened with the average Galactic extinction law, suggests a spectral type around B 3.5 V. Measured line equivalent widths suggest a spectral type between B4.5 and B5. The Ly alpha line profile, when dereddened with the average hydrogen column density, given the color excess of S Muscae, suggests a spectral type close to B5 V. Even with this uncertainty the mass obtained for the Cepheid S Mus is too low to fit on the classical evolutionary tracks as calculated by Becker, given the luminosity of S Muscae as determined from the period-luminosity-color relation for the Cepheids. This indicates excess mixing in the interiors of the main sequence progenitor of the Cepheid.

In order to study the possibility of strong mass loss, which might explain the low mass of the Cepheid S Muscae we have studied absorption lines in the ultraviolet spectrum of the S Muscae companion. For mass loss strong enough to cause a measurable reduction in the Cepheid mass we expect shortwards displaced absorption components in the companion spectrum, due to the wind from the Cepheid passing by the companion. We probably did not see such components, but possible candidates gave us an upper limit to the mass loss of less than 10^{-9} solar masses per year for any mass loss with velocities larger than 50 km/s. (For lower velocities the wind absorption lines are hidden in the stellar and interstellar absorption lines). We doubt that a low velocity wind, if it exists, can lead to a measurable reduction in mass for the Cepheid.

These studies are still in progress.

I attach a list of the accepted IUE programs and a list of the published papers related to these proposal.

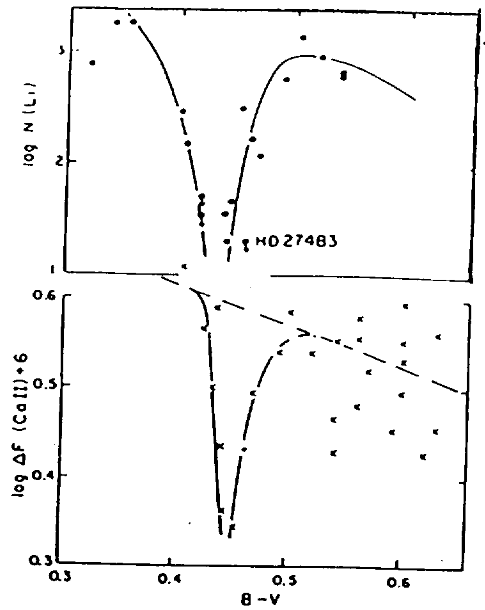

Figure 1. The Li abundances for the Hyades F stars show a dip centered at B-V=0.44 (Boesgaard and Tripicco 1986). We also show the dip in the Ca II emission line fluxes (after subtraction of the basal fluxes, see Schrijver 1987), which is centered at B-V=0.45, according to data given by Duncan *et al.* (1984). Only high quality data with more than 8 measurements were used. The dot refers to a measurement by Wilson.

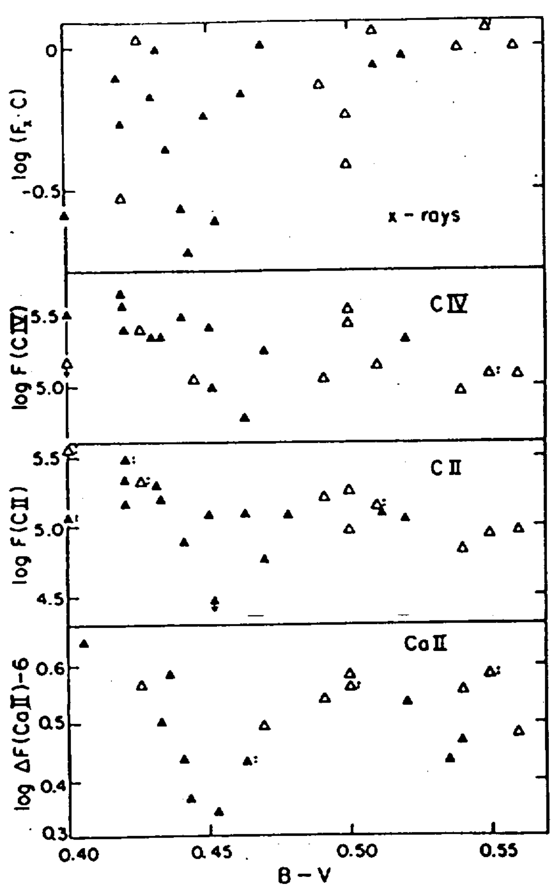

Figure 2. For the Hyades stars the measured emission fluxes of the CaII H and K lines, the CII lines at 1335 Å, the CIV lines at 1550 Å and the X-rays are plotted as a function of B-V. All the fluxes have their minimum values in the range $0.44 < B\text{-}V < 0.47$. The transition line and the coronal fluxes also show the largest scatter in this B-V range. We would like to understand the origin for this behavior. For the different wavelengths the measurements do not necessarily refer to the same stars. The filled symbols refer to single stars, the open ones to binaries. For the CaII emission the "basal" flux was subtracted. The constant $C = 10^{-28} \times R_{\odot}^2$ ergs/s.

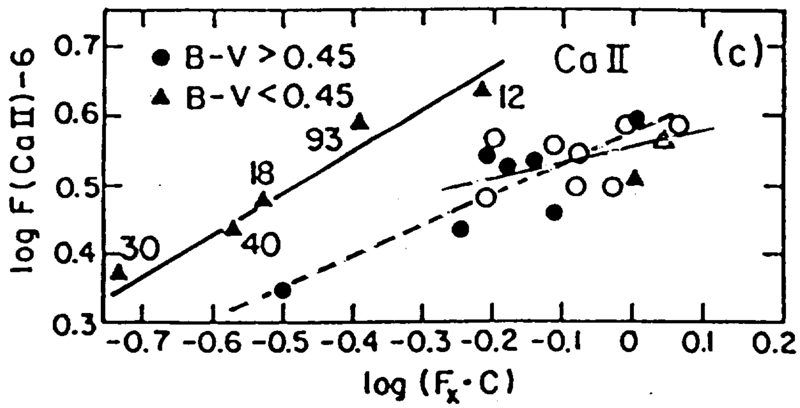

Figure 3. For Hyades main sequence stars The CaII emission line fluxes are shown as a function of the X-ray fluxes according to data given by Stern *et al.* (1995). The triangles refer to stars with B-V < 0.45, and the circles to stars with B-V > 0.45. The open symbols represent binaries, while the filled symbols represent stars which are not known to be binaries.

For B-V < 0.45 the CaII fluxes are well correlated with the X-ray fluxes, as shown by the left hand line. The numbers given for these stars tell the v sini. The increase in flux is not correlated with v sini. The governing parameter is unknown to us.

For the stars with B-V > 0.45 the X-ray flux increases abruptly by about a factor of two. The X-ray fluxes also increase much faster with increasing Ca II fluxes (short dashes). The lowest point on the right hand line refers to a star with B-V = 0.452, *i.e.*, right at the transition. Omitting this point the increase of the CaII line fluxes with increasing X-ray fluxes is indeed very small (long dashes).

We suspect that the star belonging to the one filled triangle, close to the right hand line, is actually a binary, for which the X-ray emissions are generally larger than for single stars (see Stern *et al.*).

IUE Observing Programs

Erika Böhm-Vitense

	Title	Year	US1	US2
1	Boundary of chromospheres in the HR diagram and variability of Am stars	1,2,11	18(?), 2	
2	Stellar chromospheric emission and its dependence on chem. abund. and rotation	3	7	
3	Ultraviolet emission of Herbig Haro and related objects (with K.H. Böhm)	3,4,5,6,7	3,4,3,2,2	
4	Search for White Dwarf companions of BaII and other peculiar abundance stars	3,4,5,6,7	5,4,4,2,5	
5	Search for companions of Cepheids and mass determination	4,5,6,7,10	1,4,3,5,3	
6	Evolution and mass loss in LMC and SMC clusters and NGC 6530 (with P.W. Hodge)	4,5,6	4,6,3	
7	Study of UV continuum of Pop. II Cepheids (with G. Wallerstein)	5,7	3,3	
8	Chromospheres of F star binaries with nonsynchronized rotation	5,6	2,4	
9	Study of λ Boo stars (with G. Wallerstein)	6,7	1,2	
10	UV observations of OB stars in NGC 185 and NGC 205 (with P. Hodge)	6	2	
11	Short period oscillations of Ap stars	6	1	
12	UV continua and emission lines of G and early K giants	7,10,14	4,3,3	
13	Interstellar gas and dust absorption in NGC 6530	7,11,13	4	4
14	Age dependence of the boundary line for chromospheric emission in the HR diagram	8	5	
15	Periodic light variations of α^2 CVn	8		1.5
16	The effects of Metallicity on stellar winds (with D. Boggs)	9		3
17	Mg II line profiles in W Vir	9		3
18	Masses for 4 Cepheids (with N. Evans)	10,11	4	
19	Mass loss in Pop. I Cepheids	10	3	
20	Emission lines of the long period Cepheid l Carinae	11	1	4.5
21	Blue companions of supergiants	11	2	2
22	Ultraviolet extinction in the outer Galaxy (with D. Boggs)	11		3
23	Dynamical masses for the two Cepheids S Mus and V636 Sco	11,12	10	1.5
24	UV continua of cluster OB stars in the wing of the SMC (with D. Boggs)	11	2	2
25	Companion of the RR Lyrae star TV Boo (with J. Nemec)	12	1	
26	Mass loss of B3 to B6 main sequence stars	14		1
27	Transition layers of Hyades F stars	15,16	5,7	1

Data Analysis Program

1	C and N abundances and mixing in stars	12,13		

Publications related to our accepted IUE proposals

1. "The Energy Distribution of Sirius B", Proceedings of IAU Colloquium No. 53, Rochester (1979).
2. "On the Energy Distribution in Sirius B", in: White Dwarfs and Variable Degenerate Stars, IUA Colloquium No. 53, ed. Van Horn, M. and V. Weidemann, Rochester (1979).
3. "Far Ultraviolet Energy Distributions of the Metal Poor Stars HD 109995 and HD 161817", *Ap.J.*, **243**, 213 (1980).
4. "The Boundary Line in the HR Diagram for Stellar Chromospheres and the Theory of Convection" (with T. Dettmann), *Ap.J.*, **236**, 560 (1980).
5. "Summary Talk in: Lecture Notes in Physics No. 114, Stellar Turbulence", Proceedings of IAU Colloquium No. 51, ed. Gray, D.F. and J.L. Linsky, Springer-Verlag, New York, p. 300 (1980).
6. "The White Dwarf Companion of the Barium Star ξ Cap", *Ap.J.*, **239**, L79 (1980).
7. "A Comparison of the Mg Resonance Lines in Am and Non-Am Stars of Similar Temperatures", *Astr. and Ap.*, **92**, 219 (1980).
8. "Interstellar Absorption in the MgII Resonance Line k_2 and h_2 Emissions", *Ap.J.*, **244**, 504 (1981).
9. "The Ultraviolet Energy Distributions of Late A Stars", *Ap.J.*, **244**, 938 (1981).
10. "The Chromospheric and Transition Layer Emission of Stars with Different Metal Abundances", in: "The Universe at Ultraviolet Wavelengths", NASA Conference Publication 2171, p. 303 (1981).
11. "The White Dwarf Companion of the BaII Star ξ Cap", in: "The Universe at Ultraviolet Wavelengths", NASA Conference Publication 2171, p. 455 (1981).
12. "Outlook for Ultraviolet Astronomy", in: "The Universe at Ultraviolet Wavelengths", NASA Conference Publication 2171, p. 3 (1981).
13. "The Ultraviolet Spectrum of Herbig-Haro Object 1" (with K.H. Böhm and E. Brugel), *Ap.J.*, **245**, L113 (1981).
14. "The Effective Temperature Scale", *Ann. Rev. Astr. and Astrophys.*, **19**, 295 (1981).
15. The Effective Temperatures of A and F Stars", *Ap.J.*, **255**, 191 (1982).
16. "Suggested UV Spectral Classification Criteria for A Stars", in: "Ultraviolet Spectral Classification" ESA SP-182, p. 121 (1982).
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18. "The Interstellar Absorption Lines Spectrum of μ Oph" (with J. Cardelli), *Ap.J.*, **262**, 213 (1982).
19. "The MgII Resonance Line Emission at 2800A in Stars with Different Rotational Velocities and Different Metal Abundances", *Ap.J.*, **258**, 628 (1982).
20. "The Ultraviolet Continuous and Emission Line Spectra of the Herbig-Haro Objects HH2 and HH1", *Ap.J.*, **262**, 224 (1982).
21. "An Attempt to Determine Stellar Ly α Emission Line Fluxes for F Stars with Different Metal Abundances" (with J. Woods), *Ap.J.*, **265**, 331 (1983).
22. "Ultraviolet Spectra of Herbig-Haro Objects and of the Environment of the Cohen-Schwartz Star" (with K.H. Böhm and J. Cardelli) in: Advances in Ultraviolet Astronomy, NASA Conference Publ. 2238, p. 223 (1982).
23. "Chromospheric, Transition Layer and Coronal Emission of Metal Deficient Stars" in: Advances in Ultraviolet Astronomy, NASA Conference Publ. 2238, p.231 (1982).

24. "Chromospheric, Transition Layer and X-Ray Emission for Stars with Different Rotational Velocities", in: Advances in Ultraviolet Astronomy, NASA Conference Publ. 2238, p.247 (1982).
25. "Einstein Observations of Three Classical Cepheids" (with S. Parsons), *Ap.J.*, **266**, 171 (1983).
26. "Ultraviolet Radiation from the Environment of the Cohen-Schwartz Star", *Ap.J. Lett.*, **263**, L35 (1982).
27. "Chromospheres, Transition Regions and Coronae" (Review Article), *Science*, **223**, 777, (1984).
28. "IUE Observations of Weak G Band Stars" (with C. Sneden and M. Parthasarathy), *PASP*, **96**, 44 (1984).
29. "The Problem of the Ba Stars" (with J. Nemec and C. Proffitt), *Ap.J.*, **278**, 726 (1984).
30. "On the Origin of the Ba Stars", IAU Symp. 105, p. 191 (1984).
31. "Cepheid Companions and the Masses of Cepheids" (with S. Borutzki and H. Harris), IAU Symp. 105, p. 449 (1984).
32. "Ultraviolet Studies of O and B Stars in the LMC Cluster NGC 2100, the SMC Cluster NGC 330 and in the Galactic Cluster NGC 6530", together with P. Hodge. IAU Symp. 105, pg. 59.
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34. "Blue Companions of Cepheids", in *Future of Ultraviolet Astronomy Based on Six Years of IUE Research* (FUAIUE), NASA Conf. Publ. 2349, p. 344 (with C. Proffitt) (1984).
35. "Ultraviolet Studies of the Young Populous Cluster NGC 2100 in the LMC". FUAIUE NASA Conf. Publ. No. 2349, p. 191 (together with P. Hodge and C. Proffitt) (1984).
36. "Stellar Winds in the Young Galactic Cluster NGC 6530", in FUAIUE, NASA Conf. Publ., 2349, p. 223 (with P. Hodge) (1984).
37. "Ultraviolet Observations of the Population II Cepheids ST Pup and W. Vir", in FUAIUE, NASA Conf. Publ., 2349, p. 348 (with C. Proffitt and G. Wallerstein) (1984).
38. "An Ultraviolet Study of the Star HD 112374=HR 4912", in FUAIUE, NASA Conf. Publ., 2349, p. 352 (with C. Proffitt) (1984).
39. "The White Dwarf Companion of the Mild Ba Star ξ^1Cet, in IUAIUE, NASA Conf. Publ., p. 293 (with C. Proffitt and H. Johnson) (1984).
40. "The Changing Ultraviolet Spectrum of Herbig Haro Object No. 1", in FUAIUE, NASA Conf. Publ., 2349, p. 167 (with K. H. Böhm and E. Brugel) (1984).
41. "The UV Extinction Law in Two Very Young Star Clusters, NGC 6530 in the Galaxy and NGC 2100 in the LMC", in FUAIUE, NASA Conf. Publ., 2349, p. 187 (with P. Hodge and D. Boggs) (1984).
42. "The HR Diagram for the Populous Cluster NGC 2100 in the LMC", in FUAIUE, NASA Conf. Publ., 2349, p. 191 (with P. Hodge and C. Proffitt) (1984).
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44. "The Problem of the Ba Stars", together with J. Nemec and C. Proffitt, *Ap. J.*, **278**, 726 (1984).
45. "Ultraviolet Studies of the Young Galactic NGC 6530", together with P. Hodge and D. Boggs, *Ap. J.*, **287**, 825 (1984).
46. "The Ultraviolet Spectrum of a Strongly Reddened, High Excitation Herbig Haro Object", *Ap. J.*, **277**, 216 (1984) (with K. H. Böhm).

47. "Chromospheres, Transition Regions and Coronae", *Science*, **223**, 777, 1984.
48. "Ultraviolet Analysis of the Peculiar F Supergiant HD 112374 = HR 4912, *PASP*, **96**, 897 (1984).
49. "Cepheid Masses and Cepheid Binaries", *BAAS* (1985).
50. "The Unexpected Ultraviolet Variability of Herbig Haro Object No. 1", *Ap. J.*, **292**, L75 (together with E. Brugel, K. H. Böhm, and J. M. Shull) (1985).
51. "Detection of a Compact Companion of the mild Ba Star ξ^1Cet", *Ap. J.*, **293**, 288 (together with H. Johnson) (1985).
52. "Ultraviolet Studies of Stars in the Populous Cluster NGC 2100 in the Large Magellanic Cloud", *Ap. J.*, **292**, 130 (together with P. Hodge and C. Proffitt) (1985).
53. "Cepheid Distances from Blue Main Sequence Companions", *Ap. J.*, **296**, 196 (1985).
54. "Blue Companions of Cepheids", *Ap. J.*, **296**, 175 (together with C. Proffitt) (1985).
55. "Theory of Transition Layer and Coronal Emission Measures", *BAAS*, **17**, 847, 1986.
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58. "Theory of Transition Layer and Coronal Emission Measures", IAU Symp. **122**, Circumstellar Matter, p. 359, 1986.
59. "A Possible Solution to the Cepheid Mass Problem?", Los Alamos Workshop on Stellar Pulsations. Lecture Notes in Physics No. **274**, p. 159, 1986.
60. "Theory of Transition Layer and Coronal Emission Measures", *Ap. J.*, **317**, 750, 1987.
61. "A Non-spherically Symmetric Model for the Peculiar A Star α^2 CVn", *A. J.*, **93**, 1527, 1987 (together with S. van Dyk).
62. "Intrinsically Variable Stars", Review article in *Exploring the Universe with the IUE Satellite*, ed. Y. Kondo. Reidel Publ. Comp., p. 223, 1987 (together with M. Querci).
63. "Are Most Short Period Cepheids Overtone Pulsators?", *Ap. J. (Letters)*, **324**, L27, 1988.
64. The energy input mechanism into the lower transition regions between stellar chromospheres and coronae. ESA SP-281, Vol. 1, p. 315, 1988.
65. Carbon and Nitrogen abundance determinations from transition layer lines and mixing in stars. Together with J. Mena-Werth. ESA SP-281, Vol. 1, p. 381.
66. ISM chemical abundances in two intermediate-velocity clouds in the line of sight to the SN 1987A. *A. J.*, Vol. 96, 1373, 1988, together with S. Morgan.
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68. Problems with the Baade-Wesselink Method, *Ap. J.*, **343**, 343, 1989, together with S. Morgan, P. Garnavich, M. Lawler, J. Mena-Werth, E. Peterson and S. Temple.
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70. The Dynamical Mass of S Muscae, *Astron. J.*, **99**, 353, 1990, together with M. Clark, P. Cottrell and G. Wallerstein.
71. Ultraviolet-Gas Absorption and Dust Extinction toward M8, *Ap. J.*, **358**, 441, 1990, together with Dr. Boggs.
72. Heating Mechanisms for Transition Layers in Giants, *Ap. J.*, **378**, 718, 1991, together with J. Mena-Werth.
73. Carbon and Nitrogen Abundances Determined from Transition Layer Lines, *Ap. J.*, **340**, 253, 1992, together with J. Mena-Werth.

74. Rotation and Transition Layer Emission in Giants, *A. J.*, **103**, 608, 1991.
75. Detection of a White Dwarf in a Visual Binary System, *A. J.*, **104**, 1539, 1992.
76. Absorption Line Profiles in a Companion Spectrum of a Mass Losing Cool Supergiant, L. Rodriques and E. Böhm-Vitense, *Ap. J.*, **401**, 695, 1992.
77. Emission Lines in the Long Period Cepheid ℓCarinae, together with S. Love, *Ap. J.*, **420**, 401, 1994.
78. Silicon Abundances in Population I Giants, *A. J.*, **106**, 2510, 1993.
79. Ultraviolet Studies of Cepheids, IAU Colloquium No. 139, 1992, p. 387, Invited Paper.
80. A Hot White Dwarf Companion to the Hyades Main Sequence F6 Star HD 27483, *A. J.*, **106**, 1113, 1993.
81. The Two Period Luminosity Relations for Population I Cepheids, 1993, *A. J.*, **107**, 673, 1993.
82. The Lithium Content and Other Properties of F2-F5 Giants in the Hertzsprung Gap, by G. Wallerstein, E. Böhm-Vitense, A. Vanture, and G. Gonzales, *A. J.*, **107**, 2211, 1994.
83. White Dwarf Companions to Hyades F Stars, *A. J.*, **110**, 228, 1995.
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